# Community Kiln Drying of Mountain Pine Beetle Infested Lumber for Value-added Products

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by

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## Introduction

British Columbia's Mountain Pine Beetle (*Dendroctonus ponderosae* Hopkilns) (MPB) epidemic has been described as the "worst-ever insect infestation in a North American forest" (Ministry of Forests and Range 2005). Lodgepole pine (*Pinus contorta*), the predominant commercial species in western Canada, is the major species under the MPB attack. It is estimated that about 400 million cubic metres of timber are currently affected by the MPB, and experts project that 80% of merchantable Lodgepole pine could be killed by 2013 (Ministry of Forests and Range 2006).

As the availability of Lodgepole pine wood increases and continues to increase in next decade, new products and new markets are urgently needed for this resource, other than as dimension lumber in the mature construction market in North America. One option is to use MPB-infested wood for interior finishing products to maximize the value of this material. A few remanufacturers recently started to produce panels, flooring, and furniture components in British Columbia.

Kiln drying of lumber is a critical step for downstream manufacturing. To meet the interior products standard, the lumber must be dried down below 10% before further processes. However, there is no literature available about drying MPB-infested lumber to lower moisture content for value-added interior products. This study conducted one kiln drying test at a small-capacity kiln installed at British Columbia Institute of Technology. The test was designed to be replicated in small First Nations communities so they can process MPB-infested wood that comes into their possession through the MPB salvage program.

The objective was to develop optimized drying schedules for MPB-infested wood for flooring and furniture grade with aims to minimize the degradation and lower energy costs.

## Material and Methodology

Material

The lumber for this experiment was obtained from Canfor's Rustad Sawmill in Prince George and was not graded. The logs were harvested from Supply Block E in the Prince George Forest District, 90Km northwest of Prince George. The lumber consisted of a species group, spruce-pine-fir, which represents a typical commercial sawmill product in the region. The pine is lodgepole pine that is under major MPB infestation.

Fresh-cut, rough, green lumber, 2 by 6-in by 10-ft, was delivered to the BCIT campus immediately. To prevent excessive moisture loss during handling and measurement, the lumber was end sealed with lactic paint and labeled.

Kiln sample and moisture content section

Thirty-two boards were selected randomly from the center of the initial green packs. Three kiln samples, 30-in long, and 4 moisture content sections, 1-in long, were cut and prepared from each board, as illustrated in Figure 1. Following the selection and cutting, kiln samples were end coated and labeled.

To maximize the capacity of the testing kiln, half of the charge (560 pieces of lumber) were randomly selected and cut into 8-ft lengths. After downsizing, each board was end coated again and labeled appropriately. The length of each board was recorded to determine if dimension correlated with drying defects and moisture content.

During downsizing, 1 out of every 10 boards was cut for a 1-in section, 2 ft away from one end.  All the 1-in sections, along with the 1-in. moisture section from the kiln sample boards, were oven dried to determine the initial moisture content (ASTM 2003).

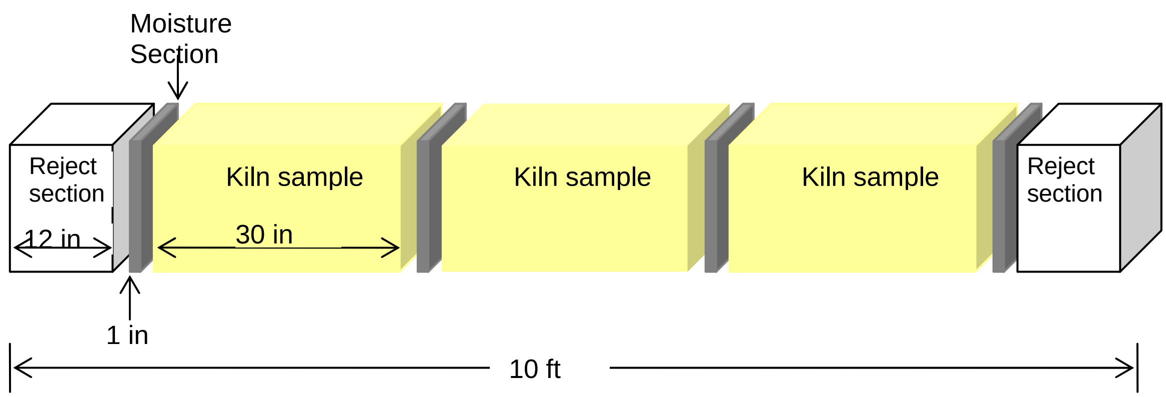


Figure 1. Illustration of kiln samples and moisture sections from one 10-foot board.

## Grading and inspection

Green lumber was graded by a certified lumber grader to Pine Furniture Grades No. 1 or No. 2 (NLGA 2003). In this study, blue stain was not considered a defect. Each board was visually scanned for six defects, including surface checks, splits, bow, twist, cup and crook. Symbols were marked on the board to designate the presence of check and split. Warp (bow, twist, cup, and crook) was measured and recorded.

Kiln drying

The lumber was hand stacked with sticks, 2 ft apart, into 8 courses and loaded into the kiln (see Photo 1). The 8 courses consisted of 4 courses of 10-ft-long boards and another 4 courses of 8-ft-long boards. The charge contained 1152 pieces of lumber, or approximately 10,368 board feet (24.46 $m^3$). Kiln samples placed in varied locations in each course were used to determine when the charge had reached the target moisture content of 10%.

The kiln used, a BCIT Prototype kiln, was essentially a small heat-and-vent type, constructed of wood frame insulated aluminum panels. The kiln utilized hot-water heat generated from a natural gas boiler. The fans were located in a plenum chamber at the top of the structure and a water sprayer was provided for re-moisturising as appropriate humidity control.

Photo 1. MPB lumber loading into the testing kiln at BCIT.

A modified conventional kiln schedule (see Table 1) was selected according to other kiln schedules using a similar heat system for softwood species (Allegretti et al. 2001 and Lawrence 2006) and adapted to the drying of value-added products with a target final moisture content of 10%. A constant fan speed of 300 fpm (1.53 m/s) that reversed very 4 hours was applied.

Table 1. Kiln schedule.

| Kiln schedule | Time (h) | Temperature (ºC) * | Relative Humidity (%) | EMC (%) |
|---|---|---|---|---|
| Warm up | 0-5 | 45(112) | 90 | 19.0 |
| 35% | 5-26 | 55(130) | 70 | 11.2 |
| 15% | 26-60 | 60(140) | 30 | 4.8 |
| (Equalizing) | 60-72 | 60(140) | 45 | 6.9 |

* numbers in parentheses are temperature in Fahrenheit.

Kiln samples were used to monitor the kiln drying in this study. When the average moisture content of kiln samples reached 10%, the drying stage ended, and the equalizing process started. After equalizing, the lumber was left in the kiln chamber, without heating for conditioning and cooling for one week before post-evaluation.

Following the cooling period, each board was evaluated for warp (bow, twist, cup, and crook), surface checks and splits, and moisture content.

The moisture content of each board, before and after drying, was recorded using Electrophysics moisture meter Model CT808. Measurements were taken 2 ft from the end as well as from the center of each board for an estimate of moisture content. Average moisture content for each board was recorded.

Checks and splits

Checks were measured up to ½-in, and splits were measured up to 1-in in length. The defects were marked and recorded. The furniture grades require sound cuttings of $66^{2}/_{3}$% on the face for grade No. 1 and 50% for grade No. 2. It is common practice that the minimal checks and splits can be chopped off without degrading the piece. In this study, checks and splits greater than 4 in were considered defects.

Warp measurement

Each board was measured twice both in the green condition and post-kiln-drying, for warps (bow, twist, cup and crook) to the nearest 1/8-in. This was done using a concrete flat floor where each board was placed and measured using a gauge as shown in Photo 2.

Photo 2. Measuring warp.

In practice, it is often difficult to precisely separate the four forms of warp (bow, twist, crook, and cup) in a given board. The common available approach is to be as fair and consistent as possible in the measurement technique from board to board (Erickson and Shmulsky 2005). Warp greater than ¼ in for an 8-ft board was classified as a defect.

When comparing the warp of two different lengths of boards, it is desirable to adjust warp to a common dimension. The methods, Formula (1) and (2), developed by Simpson and Shelly (2000) were used for adjusting crook, bow and twist measurements to a different board length (Figures 2 and 3). Cup is measured flatwise across the width of a board. As long as the width of two length groups maintained the same as 6 in, there was no need to adjust the cup measurement.

*Crook and Bow adjustment (length):*

$$w_2 = w_1 \left[ \frac{a_2}{a_1} \right]^2 \qquad (1)$$

$w_1$, $w_2$ are crook and bow of these two boards respectively.
$a_1$, $a_2$ are lengths of these two boards respectively.

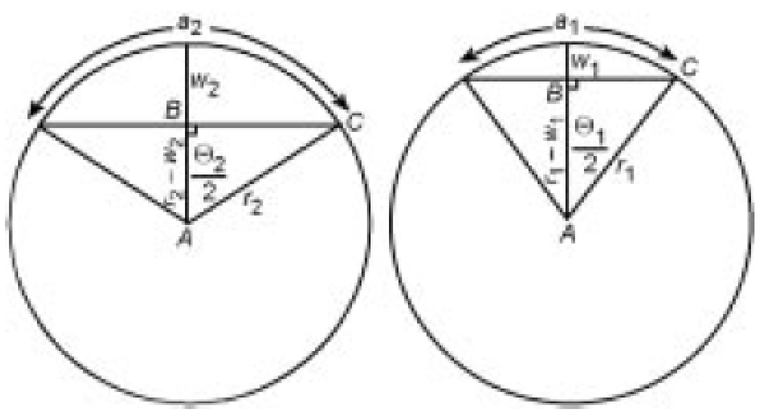


Figure 2. Two bowed or crooked boards of different lengths represented by the arcs $a_1$ and $a_2$ (courtesy Simpson and Shelly 2000).

*Twist adjustment (length):*

$$t_2 = t_1 \frac{a_2}{a_1} \qquad (2)$$

$t_1$, $t_2$ are twist of these two boards respectively.
$a_1$, $a_2$ are lengths of these two boards respectively.

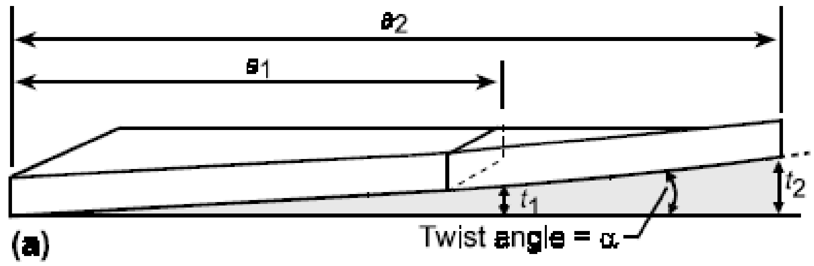


Figure 3. Relationship between twist and board length (courtesy Simpson and Shelly 2000).

The results were also analyzed in terms of the number of boards that failed to meet the maximum warp allowed in a 10-ft-long 2 by 6-in piece of lumber in the Pine Furniture Grade (NLAG 2003). The general approach was to determine if each 2 by 6 maintained the green grade after drying on the basis of meeting the warp limit of the grade.

Energy consumption

Energy consumption values included two parts: natural gas (heating) and electrical energy (air-circulation and vent actuation) used during drying. The natural gas consumption was recorded with an INVENSYS large diaphragm gas meter Model RC-750. The electricity consumption was measured with an electrical meter GE model L5.

## Results and Discussion

Species Profile

The lumber used for the drying experiment was S-P-F, a species group combining lodgepole pine, spruce, and sub-alpine fir. In total, lodgepole pine accounted for about 80% of 1120 boards. The species profile of two groups is shown in Figure 4. The 10-ft group had 84% pine, which was 10% more than the 8-ft group.

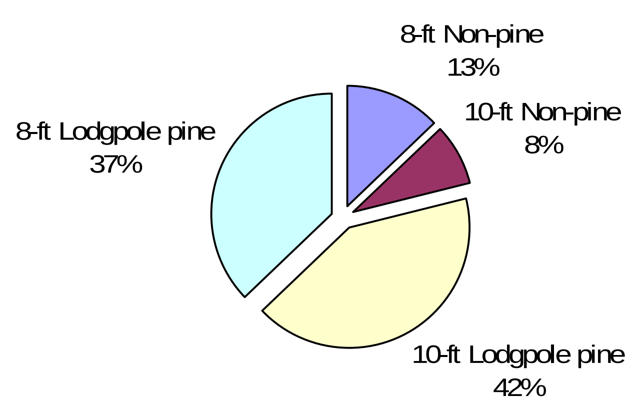


Figure 4. Species profile of S-P-F boards in 10-ft and 8-ft groups.

Moisture content by the oven-dry method

The overall average of green moisture content was 34.8% (n=88). The average moisture content of the 10-ft group (n=16) was 5.1% lower than the 8-ft group (n=72) (see Table 2). This could be caused by a higher percentage of lodgepole pine boards in the 10-ft group. The moisture content of lumber from MPB-infested trees significantly drops compared to the healthy pine lumber. This result agreed with previous findings (Chow and Obermajer 2007, Lowery 1978).

Since the sample size of each group was biased, the percentage of occurrence was used to compare the moisture content profile. Figure 5 shows the moisture content of green boards in five categories: less than 20%, 20.1-30%, 30.1-40%, 40.1-50%, and above 50%. Not surprisingly, more than 50% of the boards in each group had a moisture content of less than 30%, but only 6% of the specimens were below 20% in the 10-ft group and none were in the 8-ft group. For the higher moisture content categories, the occurrence of each group was fairly evenly distributed in the range of 13-25%.

The final average moisture content (MC) of kiln samples was 10.0% with a standard deviation of 2.28. The 8-ft group had a slightly higher MC, which corresponded to its higher initial MC.

Table 2. Average moisture content by the oven-dry method.

| Group | Green MC | Green MC <=30% | Kiln-dried MC |
|---|---|---|---|
| 10-ft | 34.6% (18.21) [a] | 50% | 9.5% (2.62) |
| 8-ft | 39.7% (22.34) | 62% | 10.4% (1.85) |
| Overall | 38.8% (21.64) | 52% | 10.0% (2.28) |

[a] numbers in parentheses are the standard deviation.

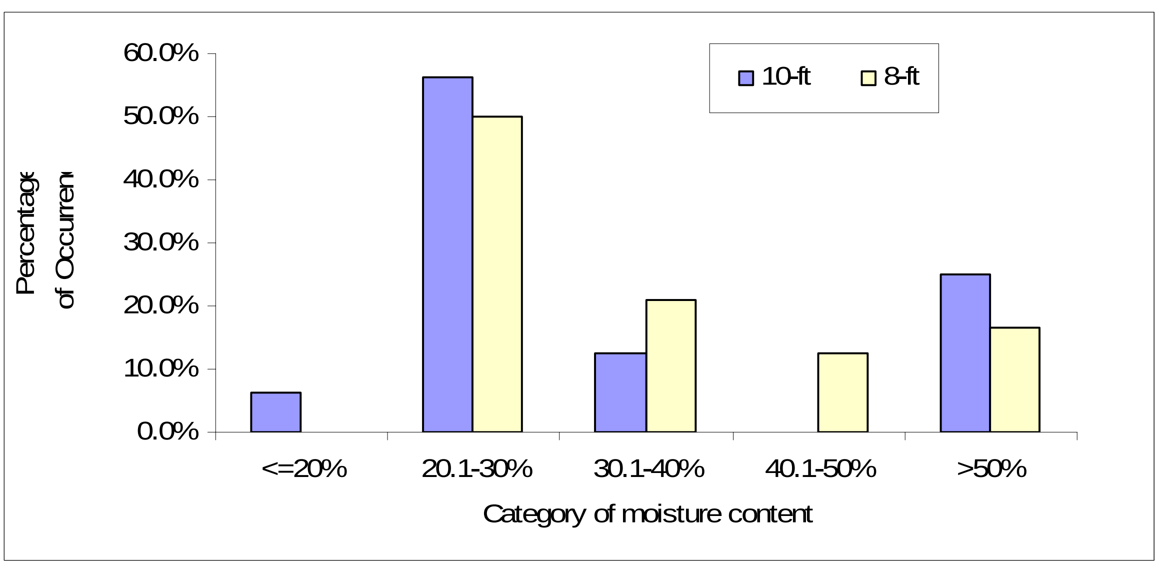


Figure 5. Evaluation of green moisture content by the oven-dry method.

Moisture content measured by the electric meter

The oven-dry and kiln sample methods provide the most accurate data for wood drying. However, it is time-consuming and destroys the sample specimens. Therefore, it is not practical for industry operation. Electric moisture meters are widely used in sawmill, kiln drying industry, and by other users because of quick data-taking and easy operation. In-line moisture detectors are popular in large sawmills for lumber moisture content measurement. However, due to the cost of investment, it is not always available for small-scale practice. In this study, a handheld electric moisture meter was also used to evaluate moisture content of each board pre- and post-kiln-drying. This measurement was desired to provide simulation data for small-scale operation.

The average MC, 35.7% (n=558), of 10-ft boards in green condition was very close to the oven-dry method (34.8%), while the average MC of the 8-ft group (n=559) was 8.3% higher than the oven-dry specimens. But the proportion of MC below 30% measured by two methods met with each other (see Table 3). The green MC in five categories is shown in Figure 6, which showed different trends comparing to the oven-dry results.

The overall average MC from post-drying boards was 6.9 (SD=2.53). This does not mean the lumber was over dried, because the moisture meter reading may be affected by many factors (James 1988). In general practice, the consistency of meter selection and application is the key to quality control. Figure 7 shows the occurrence of kiln dried board MC in five categories. Most of the boards were dried with an MC of 5-8%. Boards in the

10-ft group were slightly dryer (average MC= 6.1, SD=1.06) than ones in the 8-ft group (average MC=7.8, SD=3.19).

Table 3. Pre- and post-kiln-drying moisture content measured by the electric meter.

| Group | Green MC | Green MC <=30% | Kiln-dried MC |
|---|---|---|---|
| 10-ft | 35.7% (24.52) [a] | 60% | 6.1 (1.06) |
| 8-ft | 48.0% (25.91) | 34% | 7.8 (3.19) |
| Overall | 41.9% (25.96) | 57% | 6.9 (2.53) |

[a] numbers in parentheses are the standard deviation.

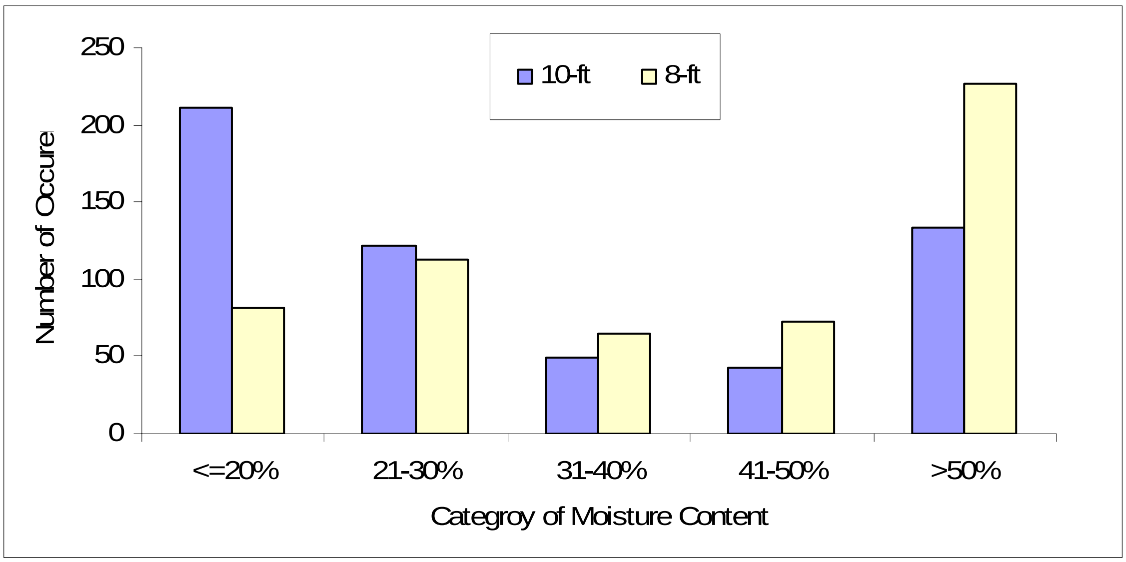


Figure 6. Evaluation of green moisture content by the electric moisture meter.

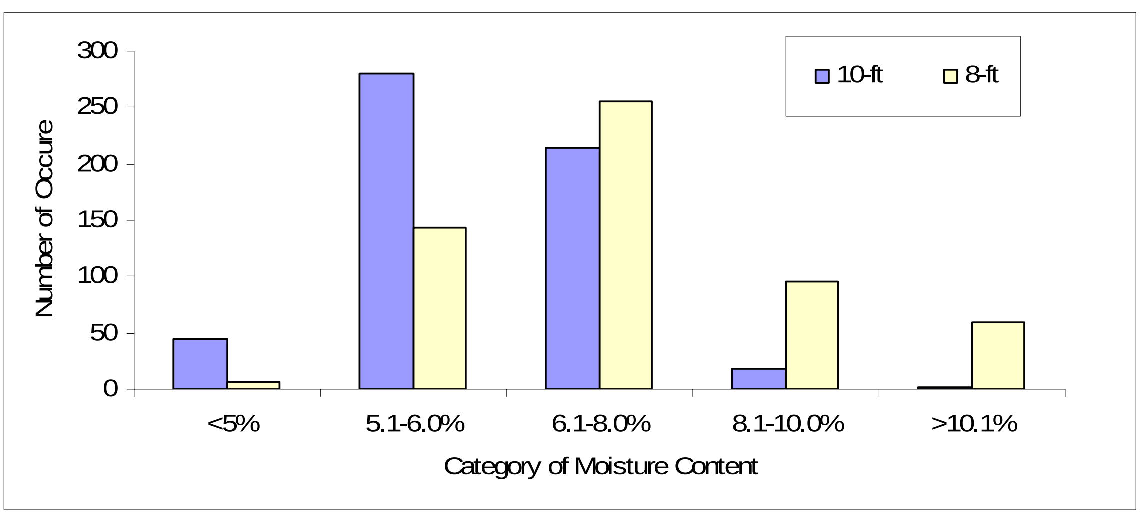


Figure 7. Evaluation of post-kiln-dry moisture content by the electric moisture meter.

Surface checking and splits

The green boards had a certain amount of surface checks. This was the result of lower MC in the green lumber. The increase in surface checks (see Table 4) in post-kiln-dry boards was within a reasonable degree, compared to a study on black cherry lumber by Scholl et al. (2005). The blue stain of the MPB wood was one factor that increased the chance of surface checking (Wengert 2006). Drying speed and low humidity at the beginning stage may also have caused surface checking (Simpson 1991). Split was a minor defect in both pre- and post-kiln-dry boards.

Surface checking in the 10-ft group was more severe than the 8-ft group in green condition. It was also a result of lower initial MC of the 10-ft group. But the increase of surface check after kiln drying remained the same, which indicated that kiln drying did not cause any difference in surface checking for both groups.

Table 4. Percentage of total number of SPF boards with drying defect.

| | Checks | | Splits | | Bow | | Twist | | Cup | | Crook | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | Pre[a] | Post[b] | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| 10-ft | 25.0 | 42.0 | 1.1 | 5.5 | 1.4 | 4.1 | 0.0 | 23.6 | 0.0 | 0.4 | 0.2 | 1.8 |
| 8-ft | 18.4 | 34.6 | 4.1 | 6.6 | 0.9 | 2.5 | 0.0 | 26.6 | 0.0 | 0.2 | 0.0 | 3.2 |
| Total | 21.7 | 38.3 | 2.6 | 6.1 | 1.2 | 3.3 | 0.0 | 25.1 | 0.0 | 0.3 | 0.1 | 2.5 |

[a] Pre refers to the percentage of the total number of boards with the drying defect before kiln drying.
[b] Post refers to the percentage of the total number of boards with the drying defect after kiln drying.

Warp

Warp results were analyzed by warp type (bow, twist, cup and crook) (see Table 5). The average of each type of warp was calculated (the percentage of occurrence in each group is shown in Table 4) and then boards with measurable warp were computed as well.

The most problematic kiln drying defect was twist. Twist occurred in 25% of boards, with a total average of 0.16 in (see Tables 4 and 5). Bow was the second-worst warp defect with an overall occurrence of 3.3%. Cup in boards was generally not significant in both groups with only 0.3% occurrence. Crook was a minor percentage across all courses with 2.3% occurrence.

Twist occurring in the 8-ft group was slightly higher (3%) than in the 10-ft group. The average measurable twist in the 8-ft group was 0.124-in higher than the 10-ft group after length adjustment.

The furniture grade recovery analyzed was only based on warp defect for the 10-ft group. Overall, 72% of boards after drying met grade No.2 and better (see Table 5).

Table 4. Warp results.

| Group | Bow | | Twist | | Cup | | Crook | |
|---|---|---|---|---|---|---|---|---|
| | Total average (in.) | Average with measurable warp (in.) | Total average (in.) | Average with measurable warp (in.) | Total average (in.) | Average with measurable warp (in.) | Total average (in.) | Average with measurable warp (in.) |
| 10-ft | 0.015 | 0.446 | 0.118 | 0.508 | 0.002 | 0.125 | 0.005 | 0.220 |
| 8-ft | 0.007 | 0.453 | 0.202 | 0.632 | 0.000 | 0.078 | 0.021 | 0.421 |
| Total | 0.011 | 0.450 | 0.160 | 0.570 | 0.001 | 0.102 | 0.013 | 0.321 |

Table 5. Furniture grade recovery.

| Group | | No.1 | | No.2 | | Grade recovery (No.2 and Better) (%) |
|---|---|---|---|---|---|---|
| | | Pre[a] | Post[b] | Pre | Post | |
| 10-ft | Occurrence | 86 | 64 | 200 | 142 | 72 |
| | % | 15 | 11 | 36 | 25 | |

[a] Pre refers to the percentage of the total number of boards with the drying defect before kiln drying.
[b] Post refers to the percentage of the total number of boards with the drying defect after kiln drying.

Energy consumption

This kiln drying test consumed total energy of 248.2Gj, in which electricity consumption was 0.84Gj, and natural gas consumption was 247.38Gj. Obviously, the heating was the major energy consumer in the kiln drying for this test. The kiln used in the test was designed to use a wood-burning boiler, so that the wood waste, which is a by-product at no additional cost in sawmills, could be used as an economical, substitute, energy source.

## Conclusions and Recommendations

One charge of MPB-infested lodgepole pine lumber was kiln dried to an MC of 10%. The grade recovery based on warp defects was 72% of No.2 and better under NLGA Pine Furniture Grade rules, as the blue stain was considered as a natural character.

Surface checking in green lumber was significant. This was mainly caused by lower MC in lodgepole pine attacked by MPB. After kiln drying, surface checking increased about 17%. In order to minimize surface checking, it is suggested that a milder kiln schedule can be used in the first stage of drying.

The major problematic kiln-drying defect was twist in this charge. Drying lumber to a lower MC will no doubt increase the warp defects due to the differential of shrinkage in various directions (tangential and radial) in wood. Other experimental kiln schedules and treatment, such as restrained drying, should be studied to minimize defects and find a correlation to a manufacturing process tolerance to twist.

About half of the boards in this drying experiment had an MC of below 30% and greater than 20%. The initial MC is one of the most critical factors in selecting kiln schedule and determining the drying conditions. Sorting green lumber by MC range, such as below and above 30%, is strongly recommended. For a small sawmill, where an in-line moisture meter is not available, a handheld electric moisture meter is an alternative option.

There was only one kiln drying test performed due to the limited amount of test material during the fiscal year of 2006-2007. Further studies and tests on kiln schedules for low moisture content need to be performed to determine the optimized practice. At least two kiln dry tests (replications) for each treatment should be considered for statistical analysis.

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